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APPLICATION OF ERTS-1 IMAGERY TO FRACTURE RELATED MINE SAFETY HAZARDS IN THE COAL MINING INDUSTRY

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Mine Safety Hazards in the Coal Mining Industry

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SUMMARY:

New fracture detail of Indiana has been observed and mapped from ERTS imagery. Studies so far indicate a close relationship between the directions of fracture traces mapped from the imagery, fractures measured on bedrock outcrops, and fractures measured in the underground mines. First-hand observations and discussions with underground mine operators indicate good correlation of mine hazard maps prepared from ERTS - aircraft imagery and actual roof falls.

The inventory of refuse piles - slurry ponds of the coal field of Indiana has identified over 225 such sites from past mining operations. These data will serve the State Legislature in making tax decisions on coal mining which take on increased importance because of the Energy Crisis.

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16. Abstract The objective of this experiment is to apply ERTS-1 imagery to geological fracture detection in glacial drift-covered areas, and to relate the location of these fractures to areas of mining hazards. This experiment takes on new significance because of increasing coal production due to the Energy Crisis. New fracture detail of Indiana has been observed and mapped from ERTS imagery. Studies have indicated a close relationship between the directions of fracture traces mapped from the imagery, fractures measured on bedrock outcrops, and fractures measured in the underground mines. First-hand observations and discussions with underground mine operators indicate good correlation of mine hazard maps prepared from ERTS - aircraft imagery and actual roof falls. The inventory of refuse piles - slurry ponds of the coal field of Indiana has identified over 225 such sited from past mining operations for the Indiana State Legislature.					
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PREFACE

The primary objective of this ERTS-1 experiment is to evaluate the application of ERTS-1 imagery and underflight aircraft photography to geological fracture detection in glacial drift-covered areas and to apply fracture data to determine areas of mining hazards prior to mining. This experiment takes on new significance because of the Energy Crisis. A secondary and increasingly significant objective is to determine remote sensor data applications to mining-produced, environmental/energy problems such as mined land reclamation, mine subsidence and acid mine drainage. ERTS imagery and high-altitude color aerial photography have been analyzed and fracture data derived from the analyses and from published sources have been compiled on a 1:250,000 scale base map. Results obtained to date indicate a close correlation between fractures detected by remote sensing and fracture measurements from underground mines and surface bedrock exposures.

An extension of the program to inventory coal preparation plant refuse piles and slurry ponds is underway and will be completed in time to provide the Spring Session of the Indiana State Legislature with factual data on the location and extent of these materials. Consideration is being given to assessing a severance tax on all coal mined to provide funds to restore sites.

A preliminary mine hazards map was compared with actual roof falls in the Kings Station Mine as indicated by mine personnel and by first-hand observation. Good correlation was found with over 4 out of 5 predicted hazard areas coinciding with areas of roof fall problems. These positive results are encouraging, but the technique needs further verification in other areas in the United States.

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Type II Report
APPLICATION OF ERTS-1 IMAGERY TO FRACTURE
RELATED MINE SAFETY HAZARDS IN THE COAL MINING INDUSTRY

1.0 INTRODUCTION

1.1 General

This document is the third Type II report submitted in association with NASA Contract Number NAS5-21795.

The primary objective of this investigation is to apply ERTS-1 imagery and complementary aircraft photography to geological fracture detection in the glacial drift-covered areas of the Indiana coal field, and to relate the location of these fractures to mining hazards. The program takes on new importance because of the Energy Crisis.

Secondary objectives are to evaluate the application of ERTS imagery and underflight data to the mapping and monitoring of other coal mining-produced environmental/energy problems such as a surface mined land inventory, reclamation progress, mine subsidence, and other environment impacting conditions.

The area studied is the Indiana coal field which lies on the east side of the Eastern Interior Coal Basin (also called the Illinois Basin); the center of the basin lies in southeastern Illinois. This

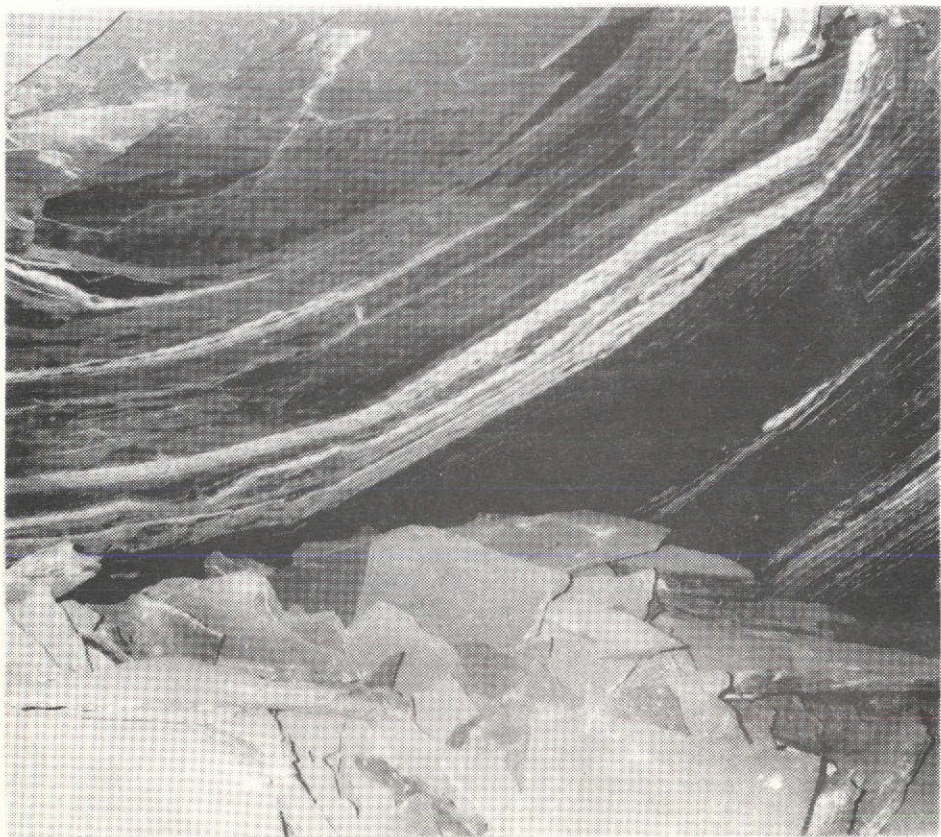
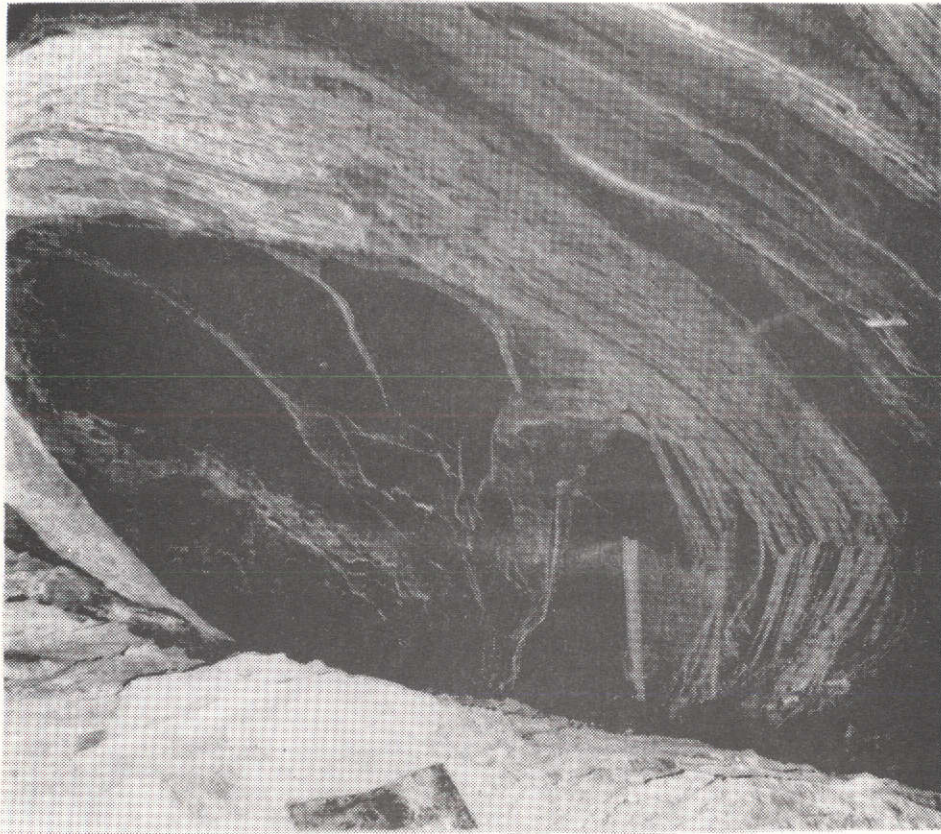
is both a structural and sedimentary basin and the coal bearing rocks in Indiana dip to the west and southwest toward the center of the basin at an average rate of 25 feet per mile. Coal deposits in Indiana occur in 25 counties in the southwestern part of the state and underlie an area of about 6,500 square miles.

Underground mining is generally more complicated than surface mining and the hazards to the miners are greater. About 75 percent of all coal mining fatalities occurred in underground mines. The U.S. Bureau of Mines identifies roof falls as the number one killer in coal mining (see Figure 1.1). More than 40 percent of the fatalities in underground mining are the direct result of roof falls and wall collapse. Any method or technique which will provide greater safety to the miners and better ensure continuous low cost coal production is desirable.

1.2 Summary of Accomplishments

- The merits of the project for the Energy Crisis were documented for NASA's ERTS Program officials.
- A field trip was made in southwestern Indiana to conduct discussions with underground mine operators, make examinations of roof falls in an underground mine, make field observations of fractures and joints, and conduct an aerial reconnaissance flight for fracture validation.
- Preliminary mine hazards prediction maps were prepared and used in discussions with mine operators. These maps served to generate operator views on the validity of data, technique of presentation and utility to the mining community. The operators were most cooperative in supplying information and ideas on the occurrence and prevention of mine roof falls.

Figure 1.1. These photographs show examples of roof falls in an underground coal mine. The top illustration is looking vertically into a conical roof fall cavity over fifteen feet in the largest dimension and nearly as deep. An associated fracture can be observed at the right end of the cavity. The bottom photograph is of a larger roof fall before the debris has been removed. A fracture extending across the top of the cavity is readily discernable. A simple roof fall of this type can cost a mine operator over \$500 to rebolt and clean up.



- Visits were made to the Old Ben Coal Company and Amax Coal Company main offices to obtain their views on the program.
- The analysis of ERTS and various aircraft imagery has been completed and final drafting of fracture maps of the Indiana portion of the Eastern Interior Coal Basin is finished. These maps present an integrated compilation of fracture data derived from ERTS and aircraft imagery and from ground measurements and will be published by the Indiana Geological Survey.
- Detailed mine hazards maps for five (5) selected mine sites have been completed.
- At the Kings Station Mine in Gibson County, the correlation between predicted areas of roof falls and actual roof falls as identified by mine personnel was exceptionally good.

2.0 FRACTURE MAPS OF THE INDIANA COAL FIELD

As an initial phase of this investigation, fracture-lineament maps were produced of the Indiana portion of the Eastern Interior Coal Basin by the analysis of both ERTS imagery and small scale aerial photography.

The area of investigation lies in the southwestern portion of the State and is covered with a varied thickness of glacial drift, except for a zone along the Ohio River. This mantle of heterogeneous material limits the direct observation of bedrock strata to a few outcrops along streams and roadcuts, and in underground and surface mine exposures.

These fracture maps, prepared at a scale of 1:250,000, provide structural data (see Figure 2.1) which can not be obtained by other methods and represent a substantial contribution to the knowledge of the geological structure of this portion of the state.

3.0 DETAILED MINE MAPS

Five mine sites in Indiana-Illinois were selected for detailed analysis and mapping. The selection of these sites is discussed in detail in the January - July 1973 Type II Report. Four of the sites are associated with underground mining and one is restricted to surface mining activities.

Thunderbird Mine - This mine prompted the development of this program as it was plagued by roof fall problems which forced the mine to be closed about 18 months ago.

Kings Station Mine - A large active mine that has local areas of roof fall problems and had several injuries and a fatality in 1972 from a roof fall. The cooperation of the mining company permitted first-hand observation of roof falls and fracturing in the mine.

Mecca Mine - Although underground mining ceased many years ago, fracture controlled stream development in this area is obvious with some channels directly identifiable on ERTS imagery. Buried stream valleys in this area were also mapped ^{1/} from tonal anomalies on high-altitude aircraft imagery.

^{1/}

Identified by Harold Hutchison, Indiana Geological Survey (personal communication, 1973)

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Wabash Mine (previously referred to as the Keensburg Mine) - This mine, just being opened in Illinois, will be extended under the Wabash River into Indiana. Mining will be at a depth of about 800 feet where roof fall and wall collapse problems can be expected to be more frequent than at shallower depths. Although the mine is situated on the Wabash River floodplain where fracture information is obscured, the timeliness of any roof fall prediction data that can be derived will be of value.

Lynnville Mine - This is actually a series of mines which were selected to determine the utility of fracture data to surface operations and specifically to ground water problems and blasting blowouts due to fracture weakened rock strata.

4.0 HAZARDS PREDICTION MAPS

Based upon detailed fracture analysis from ERTS and aircraft imagery, mine hazard maps were prepared for the five test mine sites.

Various criteria were examined and tested for the preparation of the hazards classification maps. Many lineaments mapped, particularly on ERTS imagery are believed to be zones of fractures rather than a single joint. Although the fracture represents a zone of bedrock weakness, fracture junctions are particularly significant and these were rated as the highest hazard areas.

The zone of influence around a fracture junction is somewhat arbitrary for the scale maps being produced (1:24,000); a 200 foot radius was adop-

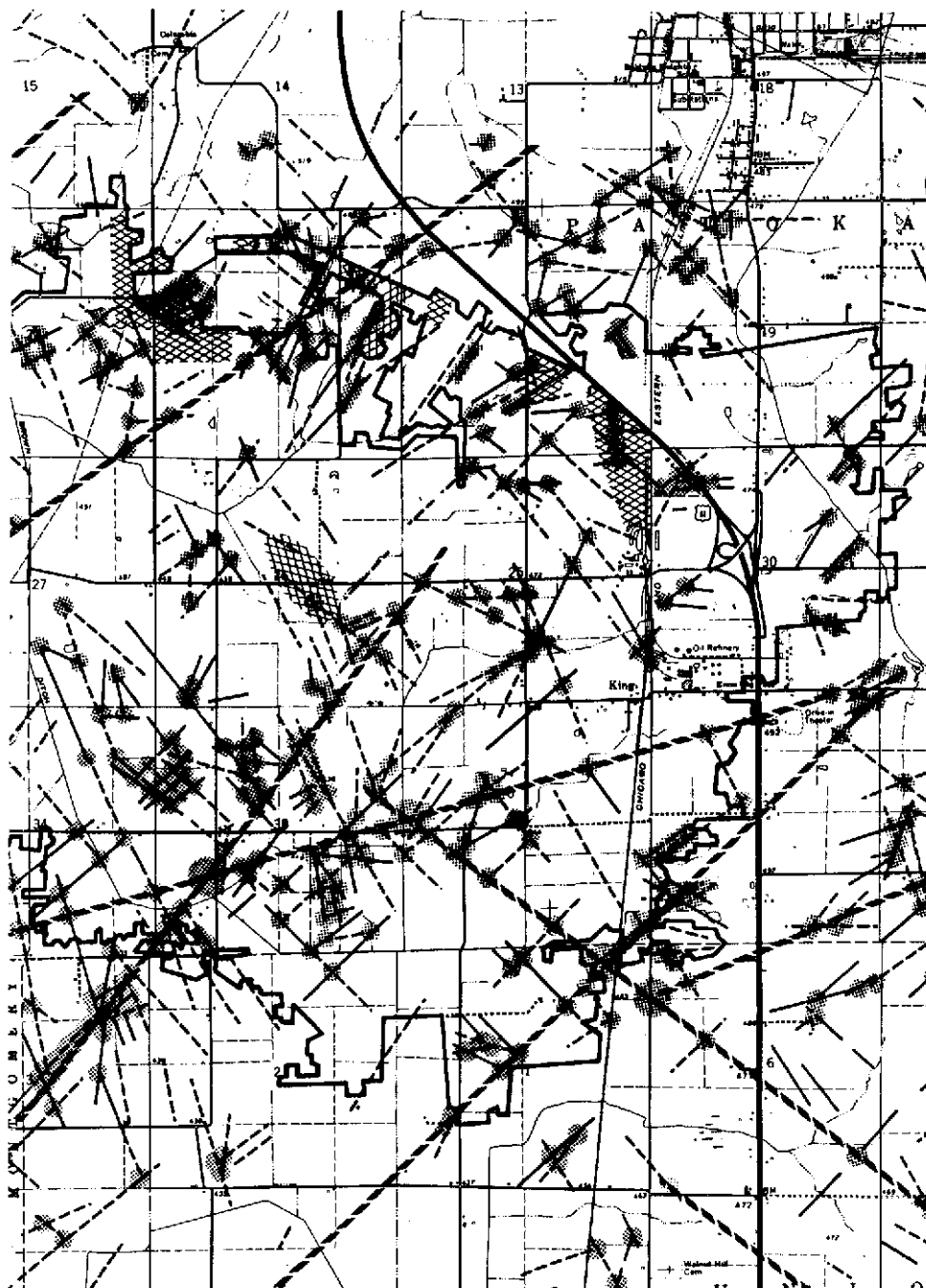
ted for airphoto mapped fractures. Realizing that probably only a portion of the fractures that exist have been mapped, and that ERTS mapped lineaments probably represent fracture zones, a 400 foot radius around ERTS mapped lineament junctions has been designated as a high hazard area. Areas more distant from mapped fractures are considered low hazard areas or areas of inadequate data.

5.0 CORRELATION OF PREDICTED ROOF FALLS WITH FIELD OBSERVATIONS

Verification of the validity of the hazards maps by underground mine data is limited by the lack of mine records and access to underground operations.

The Thunderbird Mine closed due to excessive roof fall problems just before work was initiated on this experiment. Thus, underground data is limited in this mine to measurements made by the Principal Investigator from past studies.

An underground visit to the Kings Station Mine was arranged through the courtesy of Old Ben Coal Company which provided an opportunity to make first-hand observations of roof fall problems and measurements of fractures. Prior to the visit, a preliminary hazards map was prepared. At least 4 out of 5 predicted hazards zones correlated with known roof fall areas identified by the mine officials (see Figure 5.1). Correlation of roof falls with the hazards map was limited to the north portion of the mine as the remainder of the mine has been closed-off for many years.







- | | |
|---|--|
|  Fracture-lineament mapped from ERTS-1 imagery |  Fracture mapped from aircraft imagery |
|  Predicted zones of high probability of roof falls |  Zones of severe roof fall problems in mine |

Figure 5.1. A portion of the Kings Station Mine Hazards Prediction map showing the distribution of fractures and lineaments mapped from ERTS and aircraft imagery. Stippled areas represent predicted zones of high probability of roof fall occurrence which are based on intersection of fractures. The criss-cross patterns indicate areas identified by mine personnel as having severe roof fall problems in the mine.

6.0 COAL REFUSE PILE - SLURRY POND INVENTORY

Increasing public concern for the environment has emphasized a need to remedy the environmental after-effects of all types of mining. Both surface and underground coal mining has been extensive throughout the Eastern Interior Coal Basin, and debris from such mining often contains rock materials which are toxic to the environment. These materials contain marcasite and pyrite which cause environmental degradation.

Coal processing (washing and screening) removes unwanted rock materials and coal dust. These materials are normally separated into two fractions. The larger boulder to pebble sized "gob" or refuse fraction has been disposed of in large piles as much as a mile long and many tens of feet high close to the preparation plant. The finer pebble to clay sized waste material is water-transported as a slurry and is normally piped to depressions created in mining or contained by dikes and dams (Figure 6.1).

The Buffalo Creek, West Virginia disaster in 1972 alerted states to the need for reasonably accurate records about the size and location of mined areas and the location and condition of all slurry and refuse piles.

The Indiana State Legislature will be considering a severance tax on coal in spring 1974 to provide a fund for the restoration of old refuse sites from past mining activities; however, there is a lack of adequate knowledge as to the extent and magnitude of the problem or what it will



Figure 6.1. This breached slurry containment dam in Kentucky graphically illustrates the type of problem that can develop from old coal preparation sites. Here, thousands of cubic yards of toxic waste material is being eroded into a drainage system.

cost to adequately restore these areas to an environmentally and esthetically suitable condition.

ERTS and aircraft data acquired for the Mine Safety program will be used to conduct an inventory, calculate the areal extent and estimate the cost of restoration of such sites in Indiana. This program is in progress and it is anticipated that it will be completed in time to be of use to the Governor and the spring session of the Legislature.

Interpretation of ERTS and 1:120,000 scale color infrared aerial photography has already located over two hundred and twenty-five coal refuse areas and slurry ponds within the State.

7.0 SIGNIFICANT RESULTS

The most significant result of the program was the high correlation between roof fall problem areas identified by the operators of the King Station Mine and the preliminary hazards map prepared from the analysis of ERTS and small scale aircraft imagery. (This significant result was reported in the July - August 1973 Type I report.)

The coal preparation plant site inventory (refuse pile - slurry pond inventory) of the State of Indiana is nearly finished with the identification of over two hundred and twenty five sites which are in need of some degree of restoration. These data will be provided to the Governor and State Legislature for consideration relative to the possible levy of a coal severance tax for the restoration of such features.

8.0 PROGRAM FOR THE NEXT REPORTING PERIOD

All maps, illustrations and reports will be completed in the next reporting period.

9.0 CONCLUSIONS

Although based on limited evidence, the high positive correlation between the mine hazards map of the Kings Station Mine and actual roof fall areas indicates that the technique of predicting areas of potential roof falls from ERTS and aircraft imagery is good. This is significant, not only from the point of view of mine safety, but has added significance if the current critical shortage of mine roof bolts continues.

10.0 RECOMMENDATIONS

A method of increasing the safety of underground coal mining operations and at the same time increasing production at a time of Energy Crisis is of vital concern to the nation.

The principal investigators have submitted several proposals to NASA to further apply remote sensing techniques in mine safety, mined land inventory and reclamation mapping, and mine subsidence inventory. The positive results of the current investigation appear adequate to justify furthering these efforts to refine the techniques involved for application in other coal producing areas of the United States.

APPENDICES

A P P E N D I X A

P R O J E C T T A S K S T A T U S .

TASK	STATUS	COMMENTS
PHASE III CONTINUING DATA ANALYSIS		
1.0 CONTINUE APPLICATION OF ERTS-1/ AIRCRAFT TO MINING-ENVIRONMENT STUDIES	COMPLETE	National prototype for mined land inventory has been prepared (Vincennes Quadrangle, Indiana).
2.0 ESTABLISH FRACTURE VALIDATION SYSTEM	COMPLETE	The preliminary validation system has been revised and is being applied to all imagery analysis
3.0 CONDUCT DETAILED ANALYSIS OF ERT-1/ AERIAL PHOTOGRAPHY	COMPLETE	High altitude (1:120,000 scale) aerial photography and all ERTS-imagery have been analyzed. Analysis of photography from NASA Aircraft Mission No. 210 and 230 plus U-2 Flight No. 73-008 is completed.
4.0 CONSOLIDATE FRACTURE DATA	COMPLETE	The consolidation of fracture data (reduce overlays, etc. to common base) is completed.
5.0 COMPARE UNDERGROUND AVAILABLE MINE ACCIDENT DATA TO FRACTURE ZONES	COMPLETE	Attention is being given to the Thunderbird Mine in Sullivan County where considerable fault and roof fall data has been assembled by the Principal Investigator. The Kings Station Mine has been examined and an underground visit made to collect data.
6.0 DELIMIT HAZARDOUS ZONES IN ACTIVE/ ANTICIPATED COAL MINING AREAS	COMPLETE	Several potentially hazardous areas were predicted in the Kings Station Mine preliminary to a mine visit. A visit to the mine showed good correlation.

TASK	STATUS	COMMENTS
PHASE III (Cont'd)		
6.1 ESTABLISH CRITERIA FOR DETERMINING HAZARDOUS ZONES	COMPLETE	Areas of numerous joint intersections and high density of fractures have been established as the criteria for high hazard zones.
6.2 PREPARE MAP OF EVALUA- TION OF HAZARDOUS ZONES	COMPLETE	Five (5) test mine areas have been selected for detailed fracture analysis and mapping at a scale of 1:24,000. Mapping is complete.
7.0 DEVELOP PROTOTYPE MINE SAFETY INFORMATION NETWORK	UNDERWAY	
7.1 VISIT MINE OPERATORS DISCUSS APPLICA- TIONS OF HAZARDS DATA	COMPLETE	All of the underground mining companies active in Indiana have been visited and the problems discussed.
7.2 ESTABLISH FORMAT FOR MINE SAFETY DATA DISTRIBU- TION		
7.3 DISTRIBUTE MINE HAZARDS MAP		

TASK	STATUS	COMMENTS
PHASE III (Cont'd.)		
8.0	PREPARE FINAL REPORT AND TECHNICAL BRIEFS	UNDERWAY Final report being prepared as study proceeds. Revised final report outline completed.
9.0	PREPARE COAL INDUSTRY TECHNICAL SEMINAR PROGRAM	UNDERWAY Early and very preliminary contacts made with industry representation. A seminar program is being prepared.

A P P E N D I X B

ERTS IMAGE DESCRIPTOR FORM

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE 4 January 1974

PRINCIPAL INVESTIGATOR Dr. Charles Wier

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PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	River	Lake	Lineament	
1321-16002-4,5,6,7	x	x	x	Dendritic drainage Alluvial plain Meander Strip mine Urban area
1321-15595-4,5,6,7	x	x	x	Dendritic drainage Alluvial plain Strip mine Urban area
1321-15593-4,5,6,7	x	x	x	Dendritic drainage Alluvial plain Moraine Urban area
1393-15592-4,5,6,7	x	x	x	Dendritic drainage Alluvial plain Strip mining Urban area
1428-15525-4,5,6,7	x	x	x	Urban area
1429-15575-4,5,6,7	x	x	x	Dendritic drainage
1429-15581-4,5,6,7	x	x	x	Alluvial plain
1430-16033-4,5,6,7	x	x	x	
1448-16030-4,5,6,7	x	x	x	Urban area Dendritic drainage Alluvial plain
1482-15514-4,5,6,7	x	x	x	Dendritic drainage
1482-15520-4,5,6,7	x	x	x	Urban area Alluvial plain Strip mines

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